AN INVESTIGATION OF SOME FACTORS AFFECTING THE HAND QUALITY PICKING OF SMALL OBJECTS

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ABSTRACT

AN INVESTIGATION OF SOME FACTORS AFFECTING
THE HAND QUALITY PICKING OF SMALL OBJECTS

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In the food processing industry, there is a large annual labor expense that is incurred because of the necessity of hand quality picking of small objects. The nut and coffee processors especially are faced with this problem, but as yet no scientific basis has been established that will allow decisions to be made with any degree of certainty when an attempt is made to minimize the cost of quality picking.

The purpose of this thesis was to investigate the effects of the following independent variables on the picking rate and the quality of the pickouts in the operation of hand quality picking:

1. Operator.
2. Method.
3. Position.
4. Belt Speed.
5. Damage - Density.
6. Belt Loading.
7. Replications.

A picking table was constructed and lots of objects to be picked were prepared using Great Northern beans. Four female operators were selected on the basis of their experience in hand quality picking (at least five years). Data were collected during the conduct of a factorially designed experiment that was performed in a storage room of the plant in which the operators worked. The data were analyzed by means of the conventional analysis of variance. All of the independent variables were considered as Model I (fixed level) variable in this analysis. An increment in proficiency between runs, ordered in time, precluded the classification of replications as exactly a Model I or Model II variable, thus placing a limitation on the interpretation of the interactions of those variables not completely randomized in the experiment (belt speed, belt loading, damage - density, and replication).

The results of the analysis of variance indicated that all of the independent variables that were investigated affected both of the dependent variables as a main effect or as an interaction with one or more of the independent variables.

The following conclusions were reached:

1. Operators demonstrated statistically significant differences in both picking rate and quality of picking.

2. The use of a low belt loading with the operator stationed at the side of the picking table, and using a

method in which the defective objects are tossed aside as they are grasped, produced a higher picking rate and fewer good objects in the pickouts.

In view of the results and conclusions, it was recommended that further experimentation be done using operators selected at random. It was also recommended that the operators be given sufficient training to allow them to reach the flat portion of their individual learning curves to prevent proficiency increments between runs, ordered in time. The investigation of low belt loadings, a wider range of belt speeds, lower damage - density levels, longer runs, and the use of different objects was also recommended.

Joseph J. Moder Jr.

Approved, Thesis Advisor

June 3, 1955

Date

CHAPTER I

INTRODUCTION

Importance of the Problem.--In the food processing industry, there is a large annual labor expense that is incurred because of the necessity of hand quality picking of small objects. The peanut and coffee processors especially are faced with this problem daily, but as yet no scientific basis has been established that will allow decisions to be made with any degree of certainty when an attempt is made to minimize the cost of quality picking.

A recent study has revealed that "quality picking accounts for approximately one-half of the total labor costs and about one-fifth of the total processing costs in shelling farmers' stock peanuts"(1). The United States Department of Agriculture reports that the 1952 peanut crop in this country was approximately 625,478 tons (2). Of this amount and stocks on hand, approximately 313,341 tons were milled for the edible trade market and as a result, had to be quality picked almost entirely by hand (3).

Recent investigation has shown that it costs about seven dollars to pick out one per cent of damaged peanuts, farmers' stock basis, from one ton of Spanish peanuts (4). The same investigation found that due to the difference in size and weight of Runner and Spanish peanuts, it would cost about five dollars to remove one per cent of damaged peanuts, farmers' stock basis, from one ton of Runner peanuts (5).

It is evident then that a large amount of money is spent each year on the hand quality picking of Georgia's peanut crop alone. The same type of analysis applied to all the products that have to be hand quality picked will show that this is a problem that merits considerable study and that it provides an opportunity to effect large labor savings.

An extensive study of a closely allied operation was made in California by Malcom and DeGarmo (6). This study was of the grading operation encountered in the processing for market of citrus fruits, potatoes, etc. Although the objects were no smaller than a lemon, some of their results may be used as a guide to the study of hand quality picking of small objects.

The operation of hand quality picking is briefly this: the objects to be picked are presented to the operator's view and brought within his reach by means of a moving belt. As the objects move within the operator's reach, he picks out the defective ones and places them aside.

A first consideration may indicate that the operation could be treated adequately by a motion and time study but Malcom and DeGarmo raised valid objections to this method of handling the problem.

> Usual work measurement methods such as motion and time study are of questionable value in determining labor requirements for grading as the operation is currently performed. There are two major reasons why such measurement would be difficult. First, the task is not standardized; defective specimens usually are randomly spaced and are haphazardly presented to the inspector's visual field. Second, and perhaps more important, the measurement of visual - reaction - decision time on the part of an inspector would be difficult, if not impossible, by the method suggested because grading involves subjective, internal work that is not observable by outward physical indicators. Therefore, individual time standards for grading would be difficult to determine because the grading job itself cannot be defined in terms that are completely observable and hence measurable in units of time (7).

The next most logical approach then indicates a closely controlled experiment or series of experiments to determine the significant factors involved in the operation and after these factors have been found, establish an optimum operating range for the factors that can be profitably controlled.

Investigations of several of these factors have been made; they will be considered separately.

<u>Operator's Visual Impression and Reaction Time</u>.--Since the operator must first decide upon which of the objects should be picked out, the time for a visual impression to form must be considered for it will affect the picking rate. Tests have shown that the shortest time possible for a person to see an object and get an adequate visual impression of it ranges from 0.07 second to 0.30 second, the average being 0.17 second. It was not made clear whether these times included an element used by the subject in reacting to the

impression or if impression time had been isolated in some manner (8). This is very close to the visual impression and reaction times found by eight different researchers. Their results ranged from 0.151 second to 0.225 second, the average being 0.19 second. However, these results have in them an element of time that was consumed by a muscular action such as pressing a button to signify that a visual impression had been formed (9). The exact magnitude of the visual impression and reaction time is not of primary interest in a study of hand quality picking and, although important, is beyond the scope of this investigation. Nevertheless, evidence of the existence of a minimum visual impression and reaction time indicates that there will be a maximum picking rate for each operator which normally may not be exceeded.

Illumination of the Work Place.--Illumination of the work place will affect the operation in three ways. First, insufficient illumination will contribute to operator fatigue and could result in a decrease in work output. Second, there is a relationship between intensity of illumination and visual impression time. Luckiesh (10) has found that if an object of fifty per cent contrast (reflects twice as much light as its background) can just be seen under a certain intensity of illumination when the time available for observation is 0.30 second, the intensity of illumination must be trebled if the object is to be visible when the observation time is reduced to 0.07 second. Third, the quality of the finished product will be affected by the light intensity. It is highly probable that insufficient illumination will cause more damaged objects to pass the operator and consequently reduce the quality of the outgoing product.

For best results in this type of work, an illumination level between 30 and 100 foot candles is recommended by Marks (11), the average being 65 foot candles.

Per Cent Defective Objects.--Per cent defective objects refers to the relative number of defective objects in the total number of objects. An experiment conducted at the Georgia Institute of Technology in 1953 indicated that this factor significantly affected the picking rate at the 5.0 per cent significance level[1] and that significant interactions existed between this factor and the operator at the 2.5 per cent significance level (12). The results of this experiment showed that as the per cent defective objects increased the picking rate also increased. However, the increase in picking rate was not the same for each operator. A likely reason for the increase in picking rate is that as more defective objects are presented to the operator, the operator spends less time in searching for an object to pick out, and more time in the actual picking.

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[1]This significance level will result in the probability of reporting a significant difference, when actually none exists, of less than 0.05.

Operator Position.--In the peanut processing industry today there are two operator positions in general use. Most common is the one in which the operators are stationed on both sides of a moving belt. The other requires the operator to be stationed at the end of the moving belt, thereby allowing the belt to move directly toward him (13). These two positions seem to be the most natural for the operator. Any other position would be awkward, and would perhaps accelerate fatigue. Malcom and DeGarmo (14) found that of these two positions, the second, which requires that the operator stand at the end of the belt, produced the best results in grading operations. Results in agreement with this finding were obtained by Moder and Dwyer (15) in a study of the quality picking of shelled peanuts. Direct substantiation was not achieved in these tests, however, since they incorporated a method change along with the position change. However, Barnes (16) has shown that the best method of visually controlled hand movement involves a movement along the line formed between the worker's eyes and a distant object when the worker is looking straight ahead. A displacement from this line makes the movement go slower as the displacement becomes larger. There is some evidence that the actual identification of the objects to be picked out is easier if the operator is stationed at the side of the belt instead of at the end. Kephart and Besnard (17) found indications "that the discrimination of moving objects is a much easier task when these objects are viewed from the side than when they are viewed from the end, or coming toward the subject."

In the case of quality picking objects that have different types of damage in them, Moder (18) points out that the side position, which utilizes a number of workers at each table, does have a practical advantage over the end position, which has just one worker per table. With the former method the more talented operators can be trained to pick out less easily recognizable types of damages. Thus by assigning one or more such operators to each side of each table, a superior product can be obtained.

Method of Picking.--Two methods of picking have been partially investigated. Either method may be used in either of the positions previously described. The one most prevalent in the peanut industry today consists of picking up damaged objects with both hands, palming them, and waiting until the hand is full before placing them aside. This is termed the "roll" method.

In the second method the operator picks out the damaged objects with both hands and immediately throws them aside to receptacles on either side of the belt. The objects are not retained in the hands, which explains the name "pick and throw" given to this method. A change from the "roll" to the "pick and throw" method, accompanied by a change in operator position, increased the picking effectiveness approximately 17 per cent in one instance, but it is not evident whether the increase was due to the method, position change, or both (19).

Kovac (20) investigated the effects of method on the picking rate at three different belt speeds. He found that for all three belt speeds, the use of the "pick and throw" method provided a better picking rate than did the use of the "roll" method. It is probably safe to assume that there is a significant difference in the effects of these two methods, but how much difference and under what conditions these differences may exist cannot be approximated with any degree of accuracy by using the results of research done to date.

Belt Speed.--The belt speed does not seem to affect the picking rate in the range of 16 to 60 feet per minute if the damage content is kept constant and if sufficient objects are delivered to the operator to keep him busy (21). Speeds above and below this range have not been investigated, however, and nothing can be said about their possible effects on the picking rate.

Density of Objects on the Belt.--It is possible to regulate both the number of objects that fall on the belt per unit of time and the speed of the belt. This gives rise to two important questions concerning (a) the number of objects presented to the operator per unit of time, and (b) the spacing of the objects relative to each other. The density, or number of objects per unit of area, will furnish a convenient answer to both questions when used with the belt speed.

Density is normally expressed as a per cent, and is arrived at by observing the number of objects per unit of belt area, and comparing that with what has been established as 100 per cent density. The datum, or 100 per cent density, may be arbitrarily set at any reasonable figure. However the usual method is to define 100 per cent density as the number of objects per unit of belt area, when sufficient objects have been placed on the belt so that there is room for no more without having some objects rest on top of others.

Bruckner, *et. al.* (22), disclosed that density significantly affected the picking rate at the 5.0 per cent significance level, and that there was a significant interaction between the operator and density. This means that all of the operator's picking rates were affected by changes in density, but that the effect was more pronounced for some operators than others. This study was limited by the fact that only operator, belt speed, and density were considered as variables. Therefore, these findings may or may not be valid when more variables are considered.

Work - Surface Height.--The height of the surface of the belt measured, from some reference point on the operator, should have an effect on the picking rate unless the picking operation differs greatly from other operations requiring dexterity and manipulative skill.

Barnes (23) recommends that the work-surface should be from one to three inches below the elbow of the worker for best results in assembly operations. However, there is no indication as to the origin of these figures, or what they are based upon. Ellis (24) attempted to determine the best work-surface height for manipulative operations, and came to the conclusion that for maximum performance and minimum strain to the operator, a height approximately three inches below the operator's elbow gave the best results when the arms hung naturally at the subject's side. The task that this conclusion is based upon lasted for only a short while, with rest periods between repetitions of the task. Therefore, it cannot be definitely said that a point three inches below the operator's elbow marks the best work-surface height for a sustained operation such as hand quality picking. Nevertheless, the conditions under which Ellis' study was made very closely approximate the conditions encountered in quality picking.

Operator Fatigue.--The literature includes no record of any work being done to study fatigue effects in this particular operation. However, Viteles made the following observation about fatigue effects in this general area:

> When the work involves merely strenuous muscular exertion, there may be noted a rapid and early rise in the work curve to a maximum, followed by a fairly definite fall during the morning spell. After lunch there is a fair recovery, succeeded by a progressive, well-marked fall throughout the afternoon. When the work is characterized by skill and dexterity, there

> is a slower, more gradual rise to the maximum, followed by a less obvious fall during the morning, a less complete recovery after lunch, and a much smaller drop at the close of the afternoon (25).

It is felt that with proper working conditions, the effects of fatigue on hand quality picking will be small, though not negligible.

Discussion.--All of the work done in the specific area of the hand quality picking problem has one shortcoming. Most of it represents a compromise between the classical "one variable at a time" method of experimenting and modern methods using efficient, statistically designed, experiments. This is not meant as a blanket criticism and indictment of this work. The work was good and served the purpose that it was meant to serve. However, it has very serious limitations when applied to the many varying conditions that are encountered in the area of hand quality picking of small objects. In trying to generalize principles to be followed, extreme caution should be employed when the results of the aforementioned work are used as guides.

A study is needed to determine the significant factors affecting hand quality picking. In such a study, it should be remembered that in the final analysis, an attempt should be made to establish guides for use in minimizing the cost of the operation. The conduct of the experimental work and the analysis of the data will determine the utility of the whole study.

A final word of caution: Chapanis (26) tells of an interesting phenomenon associated with the now famous Hawthorne experiments. He reminds us that "anything the experimenter did resulted in more production. It is this kind of evidence that should make us very skeptical about most factory experiments." It is wise counsel to remember this in any type of factory experimentation.

CHAPTER II

OBJECTIVE

The purpose of this thesis was to study the effects of:

1. Operator.
2. Method.
3. Position.
4. Belt speed.
5. Damage - Density.
6. Belt loading.
7. Replication.

on the:

1. Picking rate.
2. Per cent of good objects in the pickouts.

in the operation of hand quality picking of small objects.

The method used in the study was to offer the null hypotheses that each of the above named independent variables had no effect on the picking rate or the per cent of good objects in the pickouts. Then, statistical analysis of a factorial experiment was employed to determine if there was sufficient evidence to refute the hypotheses.

CHAPTER III

APPARATUS

A detailed account of the construction and calibration of the apparatus and the preparation of each of the lots of objects is furnished in Appendix I.

Picking Table

In order to control all of the variables under investigation, a special picking table was constructed consisting of the following four main parts.

Frame.--A frame was made of galvanized iron pipe to support the rest of the picking table. The details of the frame construction may be seen in Fig. 1, Appendix I.

Belt Carrier.--The belt carrier was made to form a means of presenting the objects to the operator, and to form a steady base for the working surface (See Fig. 1, Appendix I).

Hopper and Feed Control.--A reservoir for the objects and a means of feeding the objects onto the belt was constructed and mounted on the belt carrier (See Figs. 1, 2, and 3, Appendix I).

Drive.--A variable speed fluid coupling that was belted to an electric motor was used to furnish the power to drive the belt (See Fig. 1, Appendix I).

Objects

Great Northern beans were used as objects. To represent defective objects, a number of these beans were dyed red and mixed with the undyed beans. Although the red beans were not exactly the same color as are defective peanuts, it is reasonable to assume that the problems of recognition of a defective object are approximately the same in both cases.

CHAPTER IV

PROCEDURE

Variables Studied.--The following variables were studied at the indicated levels:

1. Operator.--Four

2. Method.--Two
   Method 1.--The "roll" method.
   Method 2.--The "pick and throw" method.

3. Position.--Two
   Position 1.--Operator at side of belt with belt moving from operator's left to right.
   Position 2.--Operator at end of belt with belt moving toward the operator.

4. Belt Speed.--Two
   Speed 1.--15 feet per minute.
   Speed 2.--30 feet per minute.

5. Damage - Density.--Two
   This variable is the product of the belt density and the damage content which gives the number of defective objects per linear foot of belt. Although five belt densities and three damage contents were used, examination of the following tabular presentation shows that only two damage - densities were investigated. This was due to the method in which the belt densities and damage contents were combined.

Damage - Density 1.

Density Per Cent	Damage Content Per Cent	Product
200.0	1.33	266
133.3	2.0	266
66.6	4.0	266

Damage - Density 2.

Density Per Cent	Damage Content Per Cent	Product
100.0	1.33	133
66.6	2.0	133
33.3	4.0	133

6. Belt Loading.--Three
   This is a relative variable and must be defined in relative terms. Considering the damage - density above each will have three belt loadings associated with it for the density is a measure of the belt loading.

   Loading 1.--Low
   Loading 2.--Medium
   Loading 3.--High

7. Replication.--Two
   The complete experiment was run twice.

Selection of Operators.--The operators studied were selected on the basis of their experience with the operation of hand quality picking. They were all white females, approximately 45 years old, with at least five years experience in hand quality picking. All wore glasses, and worked an eight hour day that began at 7:30 A.M. At 9:45 A.M. they had a 15 minute break. Lunch was from 11:45 A.M. to 12:15 P.M. with another 15 minute break at 2:45 P.M. They were on a straight hourly wage payment system.

Each operator was told the purpose of the experiment and any questions that they had were answered. They were also asked not to work any faster than their normal pace, since this was not a speed contest. No change of pace was noted by the observer during the experiment. The foreman in charge of the department in which the operators worked also observed each operator many times, and noted no pace changes in any of the operators. Each operator showed a very helpful attitude and seemed to be eager to cooperate in every way.

Before the actual experiment, each operator was given a $1\frac{1}{2}$ hour training session at the picking belt to allow her to become familiar with the different methods, positions, belt speeds, damage - densities, and belt loadings. In this training session, each operator completed 40 runs, each of two minutes duration. The conditions of these runs were arranged so that each of the methods, positions, damage - densities, and belt speeds was used during 20 of the runs. Thirteen of the runs were made with the low belt loading, 13 were made with the medium belt loading, and 14 were made with the high belt loading.

General Conditions.--The experiment was conducted in a storage room of the plant in which the operators worked. The room was well ventilated, adequately lighted and stayed at a comfortable temperature and humidity throughout the experiment. A light fixture that provided illumination of 75 foot candles at the working surface was suspended over the picking table.

Conduct of the Experiment.--The experimental plan was prepared prior to the actual conduct of the experiment. In an experiment of this nature there is always the possibility that some factors that have not been considered will introduce bias into the results. One of these factors is almost invariably the learning process that each of the subjects experience as the experiment progresses. To disperse the possible effects of these factors, an experiment should be conducted in a completely random manner, i.e., the previously assigned levels of each independent variable should be randomly chosen for the first and all succeeding runs. Of course, in a factorial experiment where observations are made for all possible combinations of the assigned levels of the independent variables, each choice that is made eliminates one combination of levels from the subsequent choices. However, since there were practical limitations on the availability of the operators, and the time available in which to gather the data, complete randomization was sacrificed to the following extent:

Each operator completed a replication before the next operator was used. The four combinations of method and position were used before the machine was set at a different belt speed, loading, and damage - density. Each of the combinations of belt speed, damage - density, and loading was assigned a sequence from a table of random numbers. Each of the method and position combinations was assigned a sequence within the other combination from a table of random numbers. This procedure was repeated for each operator and each replication. For the second replication, the operators were assigned their sequence randomly.

At the beginning of each operator's participation in each replication, a 15 minute period was devoted to practice in both positions, using both methods, at both belt speeds. A typical run was conducted in the following manner:

> First the belt speed, damage - density, and loading were set. Then the operator was positioned at the belt and given instructions in the method to be used. The machine was started and, on the signal "go" from the observer, the operator would begin picking. After two minutes of picking, the observer would say "stop" at which time the operator would cease picking. The machine was stopped, the pickouts counted, and the total number of pickouts, along with the number of white or "good" beans in the pickouts were recorded. During this time, which averaged two minutes, the operator was allowed to sit and relax until it was time for the next run. All runs that began with a faulty start were halted and repeated. Since the majority of faulty starts was caused by the operator's use of the method not specified for the run, they did not occur frequently. The operator stood at the belt during the two minute runs. When the time came to change damage - density levels, the lot of beans that had been in use was thoroughly mixed until the beans that had been removed from it by picking were uniformly distributed through it. To

avoid the use of the wrong sample, each lot was kept in a separate container that was clearly labeled.

Data collection covered a period from Monday morning through Thursday afternoon. Each operator completed a replication of 48 two-minute runs in one half day. The time schedule for the experiment was as follows:

Replication 1

Operator	Time
1	Monday morning
2	Monday afternoon
3	Tuesday morning
4	Tuesday afternoon

Replication 2

Operator	Time
4	Wednesday morning
2	Wednesday afternoon
1	Thursday morning
3	Thursday afternoon

Each operator's performance of each replication was completed in the same half day that it was begun and no operator's replication was interrupted by a lunch period.

CHAPTER V

ANALYSIS OF RESULTS

The analysis of the data was broken into two parts corresponding to the dependent variables that were measured; the total number of pickouts, and the per cent of good objects in the pickouts.

Total Number of Pickouts

A check on the stability of the operators was made by studying the ranges of the experimental results for the two replications made by each operator on each set of operating conditions (independent variables). This range, when treated by statistical control chart techniques, showed excellent control at about the same level of variability for each operator. Although the replications were not considered as a random variable in this experiment due to possible learning effects, the control chart analysis offers sufficient assurance that the experimental error variance is homogeneous (a necessary assumption for the subsequent analysis of variance).

In the analysis, all of the independent variables were treated as fixed variables, referred to as Model I variables in statistical nomenclature used by Mood and Davies (29 and 30). Only two of the variables could possibly have been treated as random, or Model II, variables: i.e., the four operators and the two replications. A consideration of the manner in which operators and replications were chosen did not permit the designation of these factors as random variables.[1] The analysis was not carried past the point at which estimates of the mean squares of the second order interactions were obtained. Consequently, all higher order interactions appear as portions of the residual. For the mathematical model assumed here, the expected value of each mean square contains only the error variance plus the variance due to the factor or interaction in question, and thus is correctly tested for significance against the residual (31 and 32). Since there are a total of 63 main effects and interactions to be tested for significance, the 0.01 significance level was considered necessary for rejection of the null hypotheses.[2]

The factors found to affect the picking rate are

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[1]An increment in proficiency, that is shown later in this thesis, between runs ordered in time precludes classification of replications as exactly a Model I or Model II variable. In this analysis, it will be treated as a Model I variable. This might cause estimates of interactions to be erroneously significant if the runs within a replication are not completely randomized; hence, this imposes a limitation on the validity of the results obtained with respect to the interactions of those variables not completely randomized (belt speed, belt loading, damage - density, and replications).

[2]Selection of this significance level will result in the probability of reporting a significant difference, when actually none exists, of less than 0.01.

given in Table 1. The complete table of mean squares is given in Appendix III.

Since all of the factors investigated were considered Model I variables, each mean square was tested for significance against the residual mean square.

Main Effects (See Tables 1 and 2)

Examination of Table 1 shows that each of the main effects contributes a different amount to the total variance. The discussion of these effects will be taken in the order of decreasing importance. Dashes in Table 2 indicate that the factor was not significant.

Belt Loading.--The greatest single improvement in the picking rate resulted from a change of belt loading from the high to the low level. This change caused the picking rate to be increased by 17.8 per cent of the grand average picking rate. This might have been caused by operators spending a proportionately greater amount of the available time in grasping the objects as the belt loading (number of objects on the belt) increased. The following reasons for this might be given: first, with increasing belt loading, the average distance from the defective object to the surrounding good objects will decrease. This will probably require that the operator's eyes not leave the defective object until it has been grasped by the fingers. This is probably not the case with a low belt loading, where the objects are

Table 1. Significant Factors Affecting the Picking Rate

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
O	36,221	3	12,074**
M	24,162	1	24,162**
D	2,166	1	2,166**
L	79,728	2	39,864**
R	17,200	1	17,200**
OxM	11,972	3	3,991**
OxP	3,651	3	1,217**
OxS	14,035	3	4,678**
OxD	4,644	3	1,548**
OxL	16,014	6	2,669**
OxR	4,262	3	1,421**
MxP	1,873	1	1,873*
MxS	3,432	1	3,432**
SxD	2,511	1	2,511**
OxSxD	4,305	3	1,435**
OxSxL	6,936	6	1,156**
OxSxR	2,815	3	938*
OxDxL	6,851	6	1,142**
SxLxR	3,866	2	1,933**
Residual	44,843	242	185
Total	312,928	383	134,777

** Significant at the 0.001 level.
* Significant at the 0.01 level.

O = Operator D = Damage - Density
M = Method S = Belt Speed
P = Position L = Belt Loading
R = Replication

Table 2. Significant Main Effects and First Order Interactions Expressed as a Per Cent of the Grand Average - Total Pickouts

Factor	Operator	Position		Method		Damage - Density		Belt Loading			Belt Speed		Replication	
		Side	End	Roll	Pick and Throw	Low	High	Low	Medium	High	Low	High	First	Second
Operator 1	107.2	110.4	104.0	106.6	107.7	110.5	103.9	124.1	103.5	94.1	112.1	102.3	103.3	111.1
Operator 2	99.3	99.8	98.7	90.7	107.9	99.0	99.5	103.8	97.5	96.8	97.7	100.9	96.6	102.0
Operator 3	93.0	92.8	93.1	89.7	96.3	95.7	90.2	101.9	91.1	86.0	95.8	90.1	87.0	99.0
Operator 4	100.5	99.3	101.5	96.4	104.4	99.6	101.2	110.0	97.6	82.9	97.7	103.2	99.9	101.7
Average	100.0	----	----	95.6	104.1	101.2	98.7	110.2	97.4	92.4	----	----	96.7	103.4
Method 1 Roll	----	95.4	96.4	----	----	----	----	----	----	----	98.3	93.5	----	----
Method 2 Pick and Throw	----	105.9	102.3	----	----	----	----	----	----	----	103.4	104.8	----	----
Speed 1 15 f.p.m.	----	----	----	----	----	103.4	98.3	----	----	----	----	----	----	----
Speed 2 30 f.p.m.	----	----	----	----	----	99.1	99.3	----	----	----	----	----	----	----

Grand Average - 96.2 Pickouts per Minute
---- Factor or Interaction Not Significant

relatively distant from each other. With a low belt loading, the operator might begin the search for another defective object before the last object that was identified as defective had been grasped. Second, it probably takes more time for the operator's fingers to grasp the object if there are very many good objects near it. There might be a subconscious attempt on the operator's part to move the fingers with enough precision to grasp only the defective object and leave the good objects on the belt. However, there is no experimental evidence to confirm this.

Method.--Use of the "pick and throw" method resulted in a higher average picking rate than did the "roll" method. The difference between the two methods was 8.3 per cent of the grand average picking rate. A reason for this superiority of the "pick and throw" method could be that the time spent in tossing aside objects as they are picked up is less than the time spent in palming objects as is done in the "roll" method. Also, retaining the objects in their hands could cause operators to slow their paces to avoid dropping objects during the picking operation.

Replications.--The average picking rate was better in the second replication than in the first. This was probably caused by the operators becoming more proficient at the task as the experiment progressed. The literature does not record the learning time for this operation but, evidently the time allotted for familiarization was not sufficient to allow the operators to reach a relatively flat portion of the learning curve.

Operators.--Significance of the mean square for operators shows that individual differences existed between the operators. Table 2 indicates the relative rank of each operator. It also shows that there was a difference of 14.2 per cent in the picking rates between the fastest and slowest operators. This points to the possibility of devising testing procedures that may be used in the selection of persons for the job.

Damage - Density.--The low damage - density level produced a better average picking rate than did the high level. This is contrary to what may be expected since it would seem that as the relative number of defective objects increased, the picking rate should also increase. However, the belt loadings were, on the average, 50 per cent lower for the low damage - density level. The strong effect of this belt loading overshadowed the effect of the rate at which damaged objects were presented to the operator.

First Order Interactions (See Tables 1 and 2)

In the subsequent discussion of interactions, the reader should recall the limitation placed upon the interpretation of certain interactions.[3] The first order interactions will be discussed in descending order of their

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[3]See footnote 1, page 23.

contribution to the total variance. Reference to Table 2 will show the effect of each of these interactions. Dashes in Table 2 indicate that the interaction was not significant.

Operators and Belt Speeds.--The operators reacted differently to a change in belt speed. For two operators, the low speed, 15 f.p.m. was better and for the other two the high speed, 30 f.p.m. was better. Although the belt speed was not significant as a main effect, this interaction between the operators and the belt speeds points to the possibility of increasing the picking rate by grouping operators at picking belts according to their preference of belt speeds. This would of course require extensive testing to determine the preferred belt speed for each operator.

Operators and Methods.--The "pick and throw" method was better than the "roll" method for all operators. However, the improvement varied significantly from one operator to another.

Methods and Belt Speeds.--The "pick and throw" method was better at both of the belt speeds, however, the improvement was less at a belt speed of 15 f.p.m. than at 30 f.p.m. This interaction is important since higher belt speeds will permit the use of lower belt loadings, a very important consideration since a low belt loading was the most important of the main effects.

Operators and Belt Loadings.--All of the operators did better with the low belt loading. However, as the belt loading increased, the picking rates of the operators decreased by significantly different amounts. This indicates that the increase in difficulty of picking up the defective objects was not the same for each operator.

Belt Speeds and Damage - Densities.--With the damage - density at the low level, a speed of 15 f.p.m. resulted in the best picking rate. There was not much to choose from in belt speeds when the damage - density was at the high level, however, since a belt speed of 30 f.p.m. was only one per cent of the grand average picking rate better than a speed of 15 f.p.m. It appears then that a change in belt speed has very little affect on the picking rate when the operators are confronted with objects with a high damage - density level.

Methods and Positions.--The increase in picking rate due to changing from the "roll" to the "pick and throw" method was more pronounced when the operators were picking from the side of the belt than when they were picking from the end. This increase, though slight, is encouraging since it indicates that picking from the side of the belt, which is most desirable from an operational standpoint, also results in a higher picking rate.

Operators and Damage - Densities.--Two operators performed better with the low damage - density while two performed better with the high damage - density. This also points to the possibility of placing certain operators at the end of the picking belt where the damage level is lower than at the feed end of the belt.

Operators and Replication.--All of the operators had higher picking rates in the second replication. However, operators one and three showed larger increases than operators two and four. Evidently two of the operators learned the task at a faster rate than did the other two. Since no learning curves for this task were found in the literature, it is obviously impossible to say whether the flat portion of the learning curve had been reached by any of the operators. It is possible that all of the operators were still learning at a relatively rapid rate even at the end of the second replication.

Operators and Positions.--Two operators had higher picking rates when at the side of the belt, while two had higher picking rates at the end of the belt. However, these effects were relatively small, and would not warrant the use of both picking positions in one installation.

Second Order Interactions (See Tables 1 and 3)

The second order, or three factor, interactions that involve operators indicate that the operators reacted differently with the combinations of the other two factors. This only points to the accepted fact that persons are different in their physiological and psychological composition, and consequently can be expected to react differently to identical conditions. The only significant second order interaction that did not involve operators was that between

Table 3. Significant Second Order Interactions Expressed as a Per Cent of the Grand Average - Total Pickouts

		Damage - Density		Belt Loading			Replication	
		Low	High	Low	Medium	High	First	Second
Belt Speed 1 15 f.p.m.	Operator 1	116.3	107.9	132.6	107.5	96.2	108.6	115.7
	Operator 2	99.0	96.4	101.3	96.7	95.1	96.0	99.4
	Operator 3	97.6	94.2	101.7	95.3	90.7	89.6	102.2
	Operator 4	100.7	94.7	108.4	91.2	93.5	93.7	101.7
Belt Speed 2 30 f.p.m.	Operator 1	104.7	100.0	115.5	99.6	91.9	98.2	106.5
	Operator 2	99.1	102.7	106.4	98.3	98.1	97.2	104.7
	Operator 3	93.9	86.3	103.1	87.0	81.3	84.4	95.8
	Operator 4	98.5	107.9	113.4	103.9	92.3	104.6	101.8
Damage - Density 1 Low	Operator 1	----	----	124.6	108.3	98.5	----	----
	Operator 2	----	----	107.6	98.2	91.3	----	----
	Operator 3	----	----	106.7	92.1	88.4	----	----
	Operator 4	----	----	111.4	94.8	92.6	----	----
Damage - Density 2 High	Operator 1	----	----	123.5	98.8	89.6	----	----
	Operator 2	----	----	100.1	96.7	101.9	----	----
	Operator 3	----	----	97.1	90.1	83.5	----	----
	Operator 4	----	----	110.4	100.3	93.2	----	----
Belt Speed 1 15 f.p.m.	Replication 1	----	----	104.8	93.5	92.5	----	----
	Replication 2	----	----	117.1	101.8	95.2	----	----
Belt Speed 2 30 f.p.m.	Replication 1	----	----	108.3	93.2	86.7	----	----
	Replication 2	----	----	110.3	101.1	95.1	----	----

Grand Average - 96.2 Pickouts per Minute
---- Interaction Not Significant

belt speed, belt loading, and replications. Examination of Table 3 shows that the effects of the belt speed and belt loading depended upon the replication. Dashes in this table indicate that the interaction was not significant. Although the belt speed did not appear as a significant main effect, and did not interact with the belt loading as a first order interaction, the belt speed and belt loading in combination affected the picking rate differently in the two replications. This inconsistency indicates that this factor needs additional study to determine whether this was due to random variation between replications or to systematic increments attributable to learning.

Per Cent Good in the Pickouts

An estimate of each of the operator's stability was made for the per cent good in the pickouts in the same manner that it was made for the total pickouts. These estimates, as shown in the following table, indicate that there was a marked difference in the operators' variability between replications:

Operator	Root Mean Square Estimate of Variability (Per cent good in the pickouts)
1	1.04
2	5.23
3	5.23
4	7.71

Therefore, the analysis of the per cent good in the pickouts was separated into three parts; operators two and three were included in the same analysis while operators one and four were analyzed separately. The factors that were found to significantly affect the per cent good in the pickouts are given in Table 4. The dashes in Table 4 indicate that the factor was not significant. Crosses indicate that the factor was not present in the analysis.

Consideration of the main effects and interactions that affected operator four indicated that operator four was very unstable in her performance even though in both picking rate and per cent good in the pickouts her level of performance was very near the grand average (See Tables 2 and 5). Therefore, conclusions drawn concerning the per cent good in the pickouts are not based upon data obtained from operator four. It is interesting to note, though, the number of things that affected her performance.

Main Effects (See Tables 4 and 5)

The dashes in Table 5 indicate that the factor was not significant.

Operators.--Operators two and three were significantly different in their performance.

Methods.--Only operators two and three were significantly affected by a methods change. For these two operators, a change from the "roll" to the "pick and throw" method increased the per cent good in the pickouts by 38.7 per cent of the grand average. It would seem that with this amount of improvement between the methods, operators one and four

Table 4. Significant Factors Affecting the Per Cent Good in the Pickouts

Source of Variance	Operator 1		Operators 2 & 3		Operator 4	
	Degrees of Freedom	Mean Squares	Degrees of Freedom	Mean Squares	Degrees of Freedom	Mean Squares
O	X	X	1	4971 **	X	X
M	-	-	1	837 **	-	-
P	-	-	-	-	1	190 **
S	-	-	1	1266 **	1	882 **
D	1	54.01**	1	1022 **	1	68 **
L	2	9.70*	2	841.5**	2	248.5**
R	-	-	1	323 **	1	1,496 **
OxM	X	X	1	1127 **	X	X
OxD	X	X	1	241 *	X	X
OxR	X	X	1	198 *	X	X
MxP	1	11.04*	-	-	-	-
MxR	-	-	-	-	1	39 **
PxS	-	-	-	-	1	25 **
SxD	-	-	-	-	1	79 **
SxL	-	-	2	400.5**	2	107.5**
SxR	-	-	-	-	1	244 **
DxL	-	-	-	-	2	44 **
LxR	-	-	-	-	2	18 *
MxPxD	1	10.30*	-	-	-	-
MxPxL	-	-	-	-	2	20.5*
MxPxR	1	20.39**	-	-	-	-
MxSxR	-	-	-	-	1	33 **
MxDxL	-	-	-	-	2	30 *
PxDxR	-	-	-	-	1	422 **
SxDxL	-	-	-	-	2	12.5*
SxDxR	-	-	-	-	1	55 **
SxLxR	-	-	-	-	2	170 **

Table 4. Significant Factors Affecting the Per Cent Good in the Pickouts

(Continued)

Source of Variance	Operator 1		Operators 2 & 3		Operator 4	
	Degrees of Freedom	Mean Squares	Degrees of Freedom	Mean Squares	Degrees Of Freedom	Mean Squares
DxLxR	-	-	-	-	2	94 **
Residual	38	1.34	106	22.4	38	2.4
Total	95	165.54	191	12,741.5	95	4,395.5

** Significant at the 0.001 level.
* Significant at the 0.01 level.
X Factor Not Present in the Data Analyzed.
- Factor Not Significant.

Table 5. Significant Main Effects and First Order Interactions Expressed as a Per Cent of the Grand Average - Per Cent Good in the Pickouts

	Factor	Operator	Position		Method		Damage - Density		Belt Loading			Belt Speed		Replication	
			Side	End	Roll	Pick and Throw	Low	High	Low	Medium	High	Low	High	First	Second
Main Effects	Operator 1	17.0	----	----	----	----	10.0	23.9	11.3	10.5	21.1	----	----	----	----
	Operators 2 & 3	137.9	----	----	118.5	157.2	116.4	159.2	101.7	14[illegible].5	160.2	114.0	161.0	149.8	125.8
	Operator 4	107.4	94.3	120.4	----	----	99.6	115.2	77.5	122.4	122.1	79.3	135.5	143.9	70.8
	Average	----	----	----	----	----	75.3	99.4	63.5	84.5	103.6	----	----	----	----
Interactions Operator 1	Position 1 - Side	----	----	----	21.6	15.8	----	----	----	----	----	----	----	----	----
	Position 2 - End	----	----	----	12.0	18.5	----	----	----	----	----	----	----	----	----
Interactions Operators 2 & 3	Operator 2	185.0	----	----	143.2	226.7	158.2	216.7	----	----	----	----	----	197.6	182.3
	Operator 3	90.7	----	----	93.3	87.6	79.7	101.7	----	----	----	----	----	112.1	69.7
	Speed 1 - Low	----	----	----	----	----	----	----	99.8	122.2	120.1	----	----	----	----
	Speed 2 - High	----	----	----	----	----	----	----	103.6	165.0	216.2	----	----	----	----
Interactions Operator 4	Speed 1 - Low	----	71.9	87.6	----	----	79.9	73.7	48.0	78.1	111.7	----	----	101.1	57.4
	Speed 2 - High	----	117.7	153.2	----	----	119.2	151.7	107.1	186.7	132.5	----	----	156.8	94.1
	Damage - Density 1 - Low	----	----	----	----	----	----	----	64.0	107.7	185.8	----	----	----	----
	Damage - Density 2 - High	----	----	----	----	----	----	----	90.9	137.2	117.5	----	----	----	----
	Replication 1	----	----	----	136.6	151.3	----	----	106.5	165.0	160.3	----	----	----	----
	Replication 2	----	----	----	75.3	66.4	----	----	48.6	79.9	83.9	----	----	----	----

Grand Average - 10.8 Per Cent Good in the Pickouts
---- Factor or Interaction Not Significant

would also show a difference when the method was changed. However, that was not the case. This indicates that perhaps additional methods studies should be made.

Belt Speed.--Operators two and three got fewer good objects in the pickouts at the low belt speed (15 f.p.m.), than at the higher belt speed (30 f.p.m.). As a group, operators two and three picked up 47 per cent more of the grand average good objects at the high belt speed. An increase in belt speed caused any one object to be within picking range for a shorter length of time. The decreased time available for picking any one object might have caused these operators to compensate by picking up more objects at the time to make sure that the defective objects were removed.

Damage - Density.--The low damage - density level was better for all operators than was the high level. Operator one picked up 13.9 per cent more of the grand average good objects at the high level, and operators two and three picked up 42.8 per cent more. Such results might be expected if operators tried to grasp more than one defective object at the time when the damage - density level was high (more defective objects relative to good objects) and consequently grasped one or more good objects with the defectives.

Belt Loadings.--All of the operators had a lower per cent good in the pickouts at the low belt loading. As the belt loading increased, the percentages of good in the pickouts also increased. The total increase from the low to the high belt loading was 9.8 per cent of the grand average for operator one, and 66.5 per cent of the grand average for operators two and three. This might occur if operators grasped a good object along with a defective object when the number of objects per unit of area increased (as it does when the belt loading increases).

Replications.--The performance of operator one did not change between replications. Operators two and three improved their quality of picking by 24 per cent of the grand average. This reinforces the previous suggestion that learning took place between replications since all of the operators increased their picking rate in the second replication.

First Order Interactions (See Tables 4 and 5)

The dashes in Table 5 indicate that the interaction was not significant.

Operators and Methods.--Operators two and three reacted differently when they changed methods. In changing from the "roll" to the "pick and throw" method, operator two picked up 83.5 per cent more good objects (grand average basis), while operator three picked up 6.2 per cent fewer good objects (grand average basis). This shows that perhaps the same method is not best for all operators.

Operators and Damage - Densities.--The low damage - density content was better for both operators two and three.

However, operator two picked up 63.5 per cent more good objects (grand average basis), while operator three picked up only 22 per cent more good objects (grand average basis), when the damage - density level was raised to the high value. This again seems to be the result of two different people reacting differently to identical conditions.

Operators and Replications.--Operators two and three showed different degrees of improvement in the number of good objects picked up in the second replication. Operator two picked up 5.3 per cent fewer of the grand average and operator three picked up 42.8 per cent fewer of the grand average in the second replication.

Methods and Positions.--Only operator one was affected by this interaction. When at the side of the belt, operator one picked up 5.8 per cent more of the grand average by using the "roll" method but, when at the end of the belt, she picked up 6.5 per cent more of the grand average by using the "pick and throw" method.

Belt Speeds and Belt Loadings.--At a belt speed of 15 f.p.m., the picking quality for operators two and three declined as the belt loading was increased. However, a minimum was reached at the medium belt loading. At 30 f.p.m., the picking quality of operators two and three continued to decline as the belt loading was increased. This interaction was not significant for operator one. An explanation of this effect might be found from the results of a suitably designed classical experiment involving belt speed and belt loading.

Second Order Interactions (See Tables 4 and 6)

Dashes in Table 6 indicate that the interaction was not significant.

Methods, Positions and Damage - Densities.--When operator one used the "roll" method, her picking quality decreased more with an increase in damage - density when she was at the side of the belt. When she used the "pick and throw" method, her picking quality decreased more with an increase in damage - density when she was at the end of the belt. For operators two and three, this interaction did not exist.

Methods, Positions and Replications.--In the first replications, when operator one used the "roll" method the position at the end of the belt produced better results than did the side position. When she used the "pick and throw" method, in the first replication, the side of the belt was better than was the end.

In the second replication, when operator one used the "roll" method, the end of the belt was again better than the side, however, when she used the "pick and throw" method in the second replication the side of the belt was still better though not by as large an amount as it was in the first replication. For all the other operators, this interaction did not exist.

Table 6. Significant Second Order Interactions Expressed as a Per Cent of the Grand Average - Per Cent Good in the Pickouts

		Factor	Damage - Density		Belt Loading			Replication	
			Low	High	Low	Medium	High	First	Second
Operator 1	Method 1 Roll	Position 1 - Side	10.0	33.2	----	----	----	23.2	20.1
		Position 2 - End	9.3	14.7	----	----	----	6.9	17.0
	Method 2 Pick and Throw	Position 1 - Side	10.8	20.8	----	----	----	14.7	17.0
		Position 2 - End	10.0	27.0	----	----	----	18.5	18.5
Operator 4	Method 1 Roll	Position 1 - Side	----	----	68.3	100.7	106.5	----	----
		Position 2 - End	----	----	77.6	142.4	140.1	----	----
	Method 2 Pick and Throw	Position 1 - Side	----	----	62.5	113.5	114.6	----	----
		Position 2 - End	----	----	101.9	133.2	127.4	----	----
	Method 1 Roll	Speed 1 - Low	----	----	----	----	----	89.5	68.7
		Speed 2 - High	----	----	----	----	----	183.7	81.8
	Method 2 Pick and Throw	Speed 1 - Low	----	----	----	----	----	112.7	46.3
		Speed 2 - High	----	----	----	----	----	189.9	86.4
	Method 1 Roll	Damage - Density 1 Low	----	----	59.1	103.1	141.3	----	----
		Damage - Density 2 High	----	----	86.8	140.1	105.4	----	----
	Method 2 Pick and Throw	Damage - Density 1 Low	----	----	69.5	112.3	112.3	----	----
		Damage - Density 2 High	----	----	95.0	134.3	129.7	----	----
	Replication 1	Position 1 - Side	126.6	130.4	----	----	----	----	----
		Position 2 - End	142.8	176.0	----	----	----	----	----
	Replication 2	Position 1 - Side	54.0	66.4	----	----	----	----	----
		Position 2 - End	74.9	88.0	----	----	----	----	----
	Damage - Density 1 Low	Speed 1 - Low	----	----	47.5	74.1	118.1	107.3	52.5
		Speed 2 - High	----	----	81.1	141.3	135.5	162.1	76.4
	Damage - Density 2 High	Speed 1 - Low	----	----	48.6	82.2	105.4	94.9	62.5
		Speed 2 - High	----	----	133.2	192.2	129.7	211.5	91.8
	Replication 1	Speed 1 - Low	----	----	60.2	85.7	157.5	----	----
		Speed 2 - High	----	----	152.9	244.3	153.3	----	----
	Replication 2	Speed 1 - Low	----	----	35.9	70.6	66.0	----	----
		Speed 2 - High	----	----	61.4	89.2	101.9	----	----
	Damage - Density 1 Low	Replication 1	----	----	64.5	137.8	181.9	----	----
		Replication 2	----	----	44.0	77.6	71.8	----	----
	Damage - Density 2 High	Replication 1	----	----	138.5	192.2	139.0	----	----
		Replication 2	----	----	53.3	82.2	96.1	----	----

Grand Average - 10.8 Per Cent Good in the Pickouts
---- Interaction Not Significant

Summary of Results

Generalization of the results must necessarily be limited by the conditions of the experiment. The limitations that are considered most severe are:

1. The use of only four operators.
2. Belt speeds were limited to 15 and 30 f.p.m.
3. The lowest belt loading was 33.3 per cent density.
4. The runs were of only two minutes duration.
5. The incomplete randomization of belt speeds, belt loadings, and damage - densities.
6. The use of only two replications.

The more salient points noted in the results are:

1. That all of the independent variables that were investigated had an effect on both the picking rate and the per cent good in the pickouts either as a main effect or interaction.

2. That an increasing belt loading had an adverse effect on both the picking rate and the per cent good in the pickouts.

3. That an increasing damage - density content had an adverse effect on both the picking rate and the per cent good in the pickouts. However, the true effect of the damage - density content is probably confounded with the belt loading. Reference to the definitions and levels of the variables in Chapter IV shows that a change in damage - density was always accompanied by a change in belt loading which was due to the definition given belt loading.

4. That the "pick and throw" method was better than the "roll" method, although its relative superiority depended on the operator's position at the belt. The increase in picking rate due to the use of the "pick and throw" method was greater when the operator was at the side of the belt than when she was at the end. For two of the operators, the method had no effect on the per cent good in the pickouts, although the other two operators picked up more good objects while using the "pick and throw" method.

5. That although the belt speed did not appear as a significant main effect on the picking rate, as it increased it had an adverse effect on the per cent good in the pickouts.

6. That with a fixed damage - density, the picking rate was influenced by the belt speed.

7. That the best combination of factors affecting operators' performance was:

Method-------------------"pick and throw"
Position-----------------Side of belt
Belt Speed---------------15 f.p.m.
Damage - Density---------Low
Belt Loading-------------Low

With this combination of factors a comparison by operator shows that the operators' performances were as follows:

Operator	Per Cent of the Grand Average Per Cent Good in the Pickouts (Grand Average % Good in the Pickouts = 10.8)	Per Cent of the Grand Average Picking Rate (Grand Average Picking Rate = 96.2 pickouts per minute)
1	13.9	140.0
2	125.0	118.7
3	55.6	110.7
4	32.4	114.6

The average performance of all the operators when picking with this combination of factors was 121.0 per cent of the grand average picking rate and only 56.7 per cent of the grand average of the per cent good in the pickouts.

8. That there was an increase in proficiency which varied from one operator to another, in both picking rate and quality of picking as the experiment progressed.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Any conclusions that may be drawn from this study are subject to the following limitations:

1. Only four operators were used. The method of selection and the assumption that they were fixed level variables precludes the drawing of broad inferential conclusions. It is reasonable to assume, however, that they are representative of trained industrial workers performing the job involved in this study.

2. The belt speeds were limited to the small range of 15 f.p.m. to 30 f.p.m.

3. The lowest belt loading that was investigated was 33.3 per cent density.

4. The runs lasted only two minutes each.

5. There was an increment in proficiency between runs ordered in time that might cause estimates of interactions involving those variables not completely randomized (belt speed, belt loading, damage - density, and replications) to be erroneously significant.

6. Only two replications were used.

Within these limitations, the following conclusions may be drawn:

Conclusions.--

1. That the operators demonstrated statistically significant differences in their picking rates. The mean picking rates for all tests used in this experiment were:

Operator	Mean Picking Rate
1	103.1 pickouts per minute
2	95.5 " " "
3	89.5 " " "
4	96.6 " " "

2. That the operators differ significantly in the per cent of good objects that they put in the pickouts. The mean per cent of good objects placed in the pickouts for all tests used in this experiment were:

Operator	Mean Per Cent Good in the Pickouts
1	1.8
2	19.9
3	9.8
4	11.6

3. That a comparison of the picking rates and per cent good objects in the pickouts at the different belt loadings were:

Belt Loading	Mean Picking Rate (pickouts per minute)	Mean Per Cent Good in the Pickouts
Low	106.1	6.9
Medium	93.5	10.2
High	88.9	11.2

These data show that the use of lower belt loadings will result in more favorable picking rates and a smaller per cent of good objects in the pickouts than will the use of higher belt loadings.

4. That the "pick and throw" method is superior to the "roll" method. It results in an increased picking rate, and little, if any, decrease in quality of picking. Use of the "pick and throw" method resulted in an average picking rate of 100.0 pickouts per minute, while the use of the "roll" method resulted in a picking rate of only 92.1 pickouts per minute, a difference of 7.9 pickouts per minute.

5. That an increasing belt speed will adversely affect the per cent of good objects in the pickouts. The effect of belt speed on the picking rate is a function of the damage - density of the objects on the belt. The per cent of good objects in the pickouts increased from 8.7 to 12.9 when the belt speed was increased from 15 to 30 f.p.m., an increase of 4.2 per cent.

6. That each of the variables that were investigated has an effect on both the picking rate and on the per cent of good objects in the pickouts, either as a main effect, or in interaction with one or more of the other variables.

7. That there were significant interactions between the operators and all other independent variables investigated in this study. These effects are very much smaller than the main effects. However, they indicate that complete optimization of quality picking variables for every operator in a plant is neither possible nor practical, unless there

is a choice in assigning operators to work positions where the conditions are best suited to each individual.

Recommendations.--In view of the results of this study, it is recommended that a further study of hand quality picking be directed toward:

1. The use of a larger number of operators selected at random.

2. The investigation of lower belt loadings.

3. Belt speeds both above and below the speeds investigated in this study.

4. Damage - density levels lower than the ones investigated in this study.

5. The use of objects other than Great Northern beans.

6. The use of runs of more than two minutes duration.

7. That operators selected for further study be given a longer familiarization period before the data are collected. This might eliminate systematic increments in performance as the experiment proceeds. This, in turn, would remove some of the limitations placed on the interpretation of interactions.

8. That an investigation be made to determine the effects of the direction of belt travel when the operator is picking from the side of the belt.

Comments.--It is always desirable that an experiment of this type reveal some information that may be put to use in everyday operations. A plant operator may, after carefully considering the limitations of this experiment, choose to use the results as a guide to his operations for hand quality picking small objects.

Application of the results would depend, of course, on the conditions found in the plant in question. Assume that a plant superintendent of a factory processing farmers' stock peanuts desired to improve his quality picking operation. The quality of his raw material would vary between certain limits, insofar as the damage content of the peanuts is concerned. If it were possible for him to determine the damage level of the peanuts as they reach the picking belt, he would probably take the following steps:

1. Require that all of the operators use the "pick and throw" methods.

2. Arrange to have all of the operators pick at the side of the belt.

3. Operate the picking belt with a low belt loading.

When the conditions outlined above have been met, variation in the flow rate of peanuts may be obtained by regulation of the belt speed. The incoming quality level of the peanuts together with the required outgoing quality level and the volume of production required of the plant will determine both the belt speed and the number of workers to be assigned to each picking belt.

If the plant bought shelled peanuts with known damage content, then the belt speeds and settings for the feed control could be scheduled in advance for each lot of peanuts that were to be picked. Even if the damage content of the peanuts was unknown, the use of the "pick and throw" method by operators stationed at the side of the belt would probably improve both the quality of picking and the volume of peanuts through the plant.

APPENDIX I

CONSTRUCTION AND CALIBRATION OF THE APPARATUS, AND PREPARATION OF THE OBJECT LOTS

Picking Table

The picking table was made of four component parts: the frame, belt carrier, hopper and feed control, and drive.

Frame.--The frame does not affect the operation of the table but merely supplies a support for it. Galvanized iron pipe was used for its construction, the details of which may be seen in Figure 1.

Belt Carrier.--The belt carrier actually forms the picking table (Fig. 1). It was made using 2" x 8" dressed lumber for the sides which form the main support for the table. Spacers of 2" x 4" lumber were used between the side pieces to give the table rigidity and also to provide a base for the picking surface. Four threaded steel bolts were run through the sides extending the width of the table to give added support and to keep vibration from loosening the table.

On top of the 2" x 4" main supports was placed a ½" sheet of plywood that was 13 3/4" wide. This sheet of plywood was nailed securely to the main supports with finishing nails. Because the belt must form the work surface while it is in contact with the plywood sheet, nail heads were countersunk to keep them from interfering with the belt.

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Two pulleys were turned from wood to approximately 6" diameter. Shafts were placed in each pulley by drilling a hole through the pulley axis and driving a piece of $\frac{1}{2}$" cold rolled steel rod through the hole. Then, one pulley had two holes drilled radially to the shaft. Holes were drilled in the shaft to align with the holes in the pulley and a nail was driven through the hole in the shaft and into the pulley to further secure the shaft to the pulley. This pulley was used as the drive pulley. Journal bearings were bolted to the sides of the carrier to receive the shafts.

A 15$\frac{1}{2}$' by 12" two ply plastic coated, green, endless belt was used.[1] This type of belt was selected for two reasons. First, the color was available commercially in normal trade channels and would not be as hard on the operator's eyes as would a white belt. Second, a break in the belt might have some effect on the picking rate that would not be the same for the different belt speeds.

Receptacles for the objects that had been picked out were fabricated from galvanized iron (Fig. 3). These containers were 22" long and had the back extended up and bent over to provide a backstop for objects being pitched off the belt. The tops of the backs were 4$\frac{1}{2}$" from the working surface when the containers were in position. By cutting a

[1]This type of belt is manufactured by the Buffalo Weaving and Belting Co., Buffalo, N. Y., under the trade name of "Plastex."

groove in the side pieces of the carrier, it was possible to slide the container to any position along the belt. A tin baffle was placed at the end of the belt to deflect the objects into a box as they came off the belt and to provide a support for the container when the operator was stationed at the end of the belt. When the container was at the end of the belt, it extended the same distance above the belt surface as it did when at the side position.

Hopper and Feed Control.--A hopper, with a feed control as an integral part, was made for the objects from galvanized sheet iron (Fig. 1). To support the hopper, a frame (Fig. 2) of welded angle iron was fastened to the sides of the belt carrier with wood screws. The hopper was supported by two $\frac{1}{2}$" round steel bars that were inserted through holes drilled in the sides of the hopper. Four stove bolts were placed in tapped holes in the frame to provide a means of vertical positioning and leveling for the hopper. The stove bolts were turned down on the end to allow them to extend into holes that had been drilled radially through the steel rods and to provide a flat shoulder for the rods to rest upon (Fig. 2). Lock nuts were put on the stove bolts to secure them in position after any necessary adjustment had been completed. For positive lateral adjustment of the hopper, four stove bolts were placed in tapped holes that were drilled horizontally in the frame. These stove bolts extended through the frame to the sides of the hopper and were also

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provided with lock nuts to hold them in place.

The front of the hopper, which was the side that was nearest the operator, was made one inch shorter at the bottom than the other sides and the back. This was done to allow room for the objects to feed onto the belt when the bottom of the hopper was less than the average minimum dimension of the objects from the belt. A 12" paperhanger's brush (Fig. 2) was bolted across the front of the hopper so that it extended to a point that was even with the bottom of the hopper. Two small stove bolts had been secured in holes in the brush handles so that the end of the bolts extended through the handles in a direction away from the hopper. This brush served to give an even object flow onto the belt.

A gate was made of 1/8" sheet aluminum with slots provided to allow vertical positioning along the brush (Fig. 3). This gate was calibrated at a belt speed of 15 f.p.m. Calibration marks were made with a center punch. When calibration was attempted at 30 f.p.m., it was found that the center punch marks were too large at the top to allow legible calibration marks to be made at this belt speed without interfering with the marks previously made. Therefore, it was necessary to make another gate of the same material to be used with a belt speed of 30 f.p.m. The gates were secured to the brush handles by wing nuts on the stove bolts that had been placed in the handle.

Drive.--A variable speed, fluid coupled, drive of 3/4 H.P. capacity was used for the drive to allow the belt speed to be controlled easily and rapidly (Fig. 1). A $\frac{1}{2}$ H.P. electric motor furnished power to the drive through a "V" belt.

Objects

Great Northern beans were selected as objects to be used in the experiment. These beans are representative of many of the small objects that are hand quality picked, such as coffee beans, shelled corn, and peanuts. They resist wear and decay well which is important since the objects had to be picked a great number of times. A quantity of these beans were dyed red to represent the defective objects that were to be picked out. Beans were picked at random from the entire lot, weighed, and from a total sample of 3445 beans, the average weight per bean was 0.313 grams. Three lots were then prepared from the original lot, the difference in each lot being in the damage content. Damage levels were selected at 1.33 per cent, 2.0 per cent, and 4.0 per cent by weight. The per cent by number will approach the per cent by weight when a large lot is prepared. The sizes of the prepared lots were large enough so that the per cent by number and the per cent by weight were, for practical purposes, the same.

Calibration of the Feed Control

There is no standard measure of density available.

Therefore, one hundred per cent density of objects on the belt was established by taking a section of belt one foot long and ten inches wide, placing beans on this section of belt until it was completely covered, with no beans resting on top of others, and then weighing the beans. This was repeated ten times, for a total of eleven measurements. The arithmetic mean was 292.9 grams per 120 square inches of belt surface with a standard deviation of 11.7 grams. The standard error of the mean was then computed by:

$$\text{Standard Error} = \frac{11.7}{\sqrt{11}} = 3.5 \text{ grams.}$$

This standard error which was 1.3 per cent of the mean, was considered acceptable for this purpose.

With 100 per cent density defined, one gate was calibrated to give 33.3, 66.6, 100.0, 133.3 and 200.0 per cent density at a belt speed of 15 feet per minute; the other gate was calibrated to give the same densities at a belt speed of 30 feet per minute. The calibration marks were not made on the gates until ten consecutive one foot sections of the belt gave densities within 1.3 per cent of the required densities.

APPENDIX II

LEGEND FOR TABLE 7.

O1 ----------------------------Operator 1

O2 ----------------------------Operator 2

O3 ----------------------------Operator 3

O4 ----------------------------Operator 4

M1 ----------------------------The "roll" method

M2 ----------------------------The "pick and throw" method

P1 ----------------------------Position at side of belt

P2 ----------------------------Position at end of belt

L1 ----------------------------Low belt loading

L2 ----------------------------Medium belt loading

L3 ----------------------------High belt loading

D1 ----------------------------Low damage - density

D2 ----------------------------High damage - density

S1 ----------------------------Belt speed of 15 f.p.m.

S2 ----------------------------Belt speed of 30 f.p.m.

R1 ----------------------------First replication

R2 ----------------------------Second replication

Table 7. Copy of the Original Data

				C 1				C 2				C 3				C 4			
				M 1		M 2		M 1		M 2		M 1		M 2		M 1		M 2	
				P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2
R 1	S 1	D 1	L 1	257 1	234 0	259 2	246 1	175 11	182 16	222 38	204 29	186 13	192 10	193 13	196 11	197 13	214 11	199 10	223 22
			L 2	217 3	211 1	216 1	215 1	169 23	177 32	215 35	210 51	161 12	150 12	192 17	177 14	148 9	148 10	177 13	164 17
			L 3	164 2	185 2	188 1	174 1	170 27	170 28	187 35	168 32	171 13	173 13	158 13	163 13	165 39	188 40	212 38	202 45
		D 2	L 1	239 5	240 3	238 2	243 7	164 42	164 33	216 56	161 55	183 21	158 18	188 14	156 15	148 9	205 10	188 9	181 16
			L 2	195 6	204 3	197 4	185 7	173 32	169 32	193 55	165 42	164 20	190 25	169 23	159 18	164 14	153 12	169 18	166 26
			L 3	162 4	161 2	172 1	163 5	182 8	184 17	221 28	206 27	154 10	154 31	163 16	177 17	173 13	163 21	176 25	166 31
	S 2	D 1	L 1	243 2	224 2	257 3	210 3	176 18	186 20	221 26	217 39	193 8	181 10	215 15	244 10	172 5	210 31	200 29	224 28
			L 2	177 3	186 1	209 2	172 2	151 18	178 24	198 42	174 38	139 19	157 24	160 24	164 32	178 40	178 38	206 45	203 49
			L 3	183 3	165 3	194 6	166 4	140 32	154 32	202 51	171 57	144 17	137 19	153 23	169 24	145 30	160 38	163 27	175 23
		D 2	L 1	223 2	199 1	217 3	218 1	172 16	168 21	208 41	226 41	168 24	161 31	202 26	181 24	232 52	211 39	236 36	278 86
			L 2	164 6	148 0	184 6	170 8	174 60	192 38	200 50	162 76	142 19	168 28	150 10	146 30	212 48	212 86	238 56	262 90
			L 3	180 18	140 0	186 8	140 5	166 58	176 42	246 86	240 116	138 30	138 24	128 32	122 44	160 16	166 30	192 38	220 40
R 2	S 1	D 1	L 1	273 1	273 3	279 6	249 2	196 26	213 14	235 24	212 29	197 8	203 5	233 11	238 14	216 5	223 10	242 6	226 13
			L 2	215 3	217 0	221 2	218 4	172 20	173 15	204 39	192 44	184 9	194 10	211 8	212 7	184 7	204 27	203 23	184 11
			L 3	215 3	215 2	224 4	191 1	169 24	171 22	199 51	188 38	175 7	179 14	203 12	169 8	194 15	154 9	191 6	174 6
		D 2	L 1	257 5	172 6	256 3	263 3	188 27	184 9	212 49	205 35	189 5	196 4	217 8	197 7	221 10	219 12	225 7	211 9
			L 2	229 10	194 7	202 7	180 5	163 19	170 23	205 51	227 55	185 12	196 15	192 5	192 7	190 13	179 20	191 9	177 7
			L 3	180 5	160 3	189 4	170 9	158 34	169 27	195 48	193 68	196 20	166 17	202 10	190 6	178 17	167 23	173 9	163 13
	S 3	D 1	L 1	209 2	214 2	191 2	219 4	193 13	199 10	241 34	243 36	176 13	206 19	231 19	203 8	197 11	214 20	225 16	248 13
			L 2	216 2	209 3	223 3	220 2	139 17	184 23	224 42	215 42	173 11	170 14	200 14	194 16	165 8	176 19	193 15	210 19
			L 3	186 4	180 5	204 0	175 2	176 32	166 21	204 61	207 81	170 32	198 52	156 24	206 20	181 14	171 23	194 17	172 20
		D 2	L 1	214 4	230 4	278 12	221 2	176 10	199 30	230 30	221 58	167 15	176 9	213 16	208 9	192 15	207 12	223 12	223 27
			L 2	193 14	132 4	214 4	195 5	184 50	172 28	210 88	230 86	182 16	188 26	200 14	166 16	180 20	204 22	198 20	194 22
			L 3	206 4	186 6	184 6	172 6	176 36	166 44	238 86	222 98	140 26	166 9	174 24	164 14	168 10	196 24	186 20	204 34

Top Figure in Each Cell - Total Number of Pickouts Per Two Minutes
Bottom Figure in Each Cell - Total Number of Good in the Pickouts

SAMPLE CALCULATIONS

Total Number of Pickouts.--In calculating the sums of squares, the following notations were used:

Factor	Number of Levels	Subscript
O = Operator	I	i
M = Method	J	j
P = Position	K	k
S = Belt Speed	L	l
D = Damage - Density	M	m
L = Loading	N	n
R = Replication	O	o

$$\text{Correction Term} = \frac{\sum S^2_{\cdots\cdots\cdot}}{IJKLMNO}$$

$$= \frac{(-2888)^2}{384} = 21,720$$

This term is used to correct all the sums of squares and is necessary because the deviations are from a mean value that is not zero. It is the sum of the individual values squared divided by the total number of observations. The negative sign results from coding the data by subtracting 200 pick-outs from each reading.

$$\text{Total SS} = \sum X^2_{ijklmno} - \text{C.T.}$$

$$= 334,648 - 21,720 = 312,928$$

This term is the result of squaring each individual value, summing these squares and subtracting the correction term.

Main Effects.--

$$SS^{O} = \frac{\sum_{i} S^2_{i......}}{JKLMNO} - C.T.$$

$$= \frac{(614)^2 + (-849)^2 + (-2014)^2 + (-639)^2}{2x2x2x2x3x2} - 21,720$$

$$= \frac{5,562,314}{96} - 21,720 = 36,221$$

This term, when divided by its degrees of freedom, is the mean square for the operator main effect.

First Order Interactions.--

$$SS^{OM} = \frac{\sum_{ij} S^2_{ij.....}}{KLMNO} - \frac{\sum_{i} S^2_{i......}}{JKLMNO} - \frac{\sum_{j} S^2_{.j.....}}{IKLMNO} + C.T.$$

$$= \frac{(258)^2 + (356)^2 + (-1220)^2 + (371)^2 + (-1316)^2 +}{2x2x2x3x2}$$

$$\frac{(-698)^2 + (-689)^2 + (50)^2}{2x2x2x3x2} - 57,941 - 45,882 + 21,720$$

$$= \frac{4,515,622}{48} - 57,941 - 45,882 + 21,720 = 11,972$$

This term, when divided by its degrees of freedom, is the mean square for the first order interaction involving operators and methods.

Second Order Interactions.--

$$SS^{OMP} = \frac{\sum_{ijk} S^2_{i\,jk....}}{LMNO} - \frac{\sum_{ij} S^2_{ij.....}}{KLMNO} - \frac{\sum_{ik} S^2_{i.k....}}{JLMNO}$$

$$- \frac{\sum_{jk} S^2_{.jk....}}{ILMNO} + \frac{\sum_{i} S^2_{i......}}{JKLMNO} + \frac{\sum_{j} S^2_{.j.....}}{IKLMNO} +$$

$$\frac{\sum_{k} S^2_{..k....}}{IJLMNO} - C.T.$$

$$= \frac{(222)^2 + (382)^2 + (36)^2 + (-26)^2 + (-666)^2 + (294)^2 +}{2x2x3x2}$$

$$\frac{(-554)^2 + (77)^2 + (-723)^2 + (-297)^2 + (-593)^2 +}{2x2x3x2}$$

$$\frac{(401)^2 + (-411)^2 + (-10)^2 + (-278)^2 + (60)^2}{2x2x3x2}$$

$$- 94,075 - 62,167 - 48,330 + 57,941 + 45,882 + 22,295 - 21,720$$

$$= \frac{2,413,310}{24} - 94,075 - 62,167 - 48,330 + 57,941 +$$

$$45,882 + 22,295 - 21,720 = 381$$

This term, when divided by its degrees of freedom, is the mean square for the second order interaction involving operators, methods and positions.

The same types of notations and calculations were used in the analysis of the per cent good in the pickouts.

Since we are dealing with all Model I variables, the significance test applied in all cases was the variance ratio or F test where MS_A is the mean square of the factor being tested and MS_R is the mean square of the residual.

$$F = \frac{(MS)_A}{(MS)_R}$$

For example, to determine if the two methods were significantly different in regard to the total number of pickouts, the mean squares and the degrees of freedom of both the methods and residual must be known:

	Mean Squares	Degrees of Freedom
Method	24,162	1
Residual	185	242

For the two methods to be significantly different at the 0.01 significance level, the following condition must exist:

$$F = \frac{(MS)_{\text{methods}}}{(MS)_{\text{residual}}} \geq 6.63$$

$$F = \frac{24,162}{185} = 130 > 6.63$$

Therefore the methods are significantly different at the 0.01 level of confidence.

APPENDIX III

Table 8. Analysis of Variance of the Picking Rate

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
O	36,221	3	12,074**
M	24,162	1	24,162**
P	575	1	575
S	1,034	1	1,034
D	2,166	1	2,166**
L	79,728	2	39,864**
R	17,200	1	17,200**
OxM	11,972	3	3,991**
OxP	3,651	3	1,217**
OxS	14,035	3	4,678**
OxD	4,644	3	1,548**
OxL	16,014	6	2,669**
OxR	4,262	3	1,421**
MxP	1,873	1	1,873*
MxS	3,432	1	3,432**
MxD	79	1	79
MxL	391	2	196
MxR	3	1	3
PxS	425	1	425
PxD	83	1	83
PxL	377	2	189
PxR	16	1	16
SxD	2,511	1	2,511**
SxL	378	2	139
SxR	254	1	254
DxL	1,072	2	536
DxR	44	1	44
LxR	376	2	188
OxMxP	381	3	127
OxMxS	424	3	141
OxMxD	668	3	223
OxMxL	1,310	6	218
OxMxR	1,611	3	537
OxPxS	1,587	3	529

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 8. Analysis of Variance of the Picking Rate

(Continued)

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
OxPxD	282	3	94
OxPxL	1,177	6	196
OxPxR	720	3	240
OxSxD	4,305	3	1,435**
OxSxL	6,936	6	1,156**
OxSxR	2,815	3	938*
OxDxL	6,851	6	1,142**
OxDxR	1,455	3	485
OxLxR	3,048	6	508
MxPxS	15	1	15
MxPxD	59	1	59
MxPxL	139	2	70
MxPxR	45	1	45
MxSxD	260	1	260
MxSxL	362	2	181
MxSxR	26	1	26
MxDxL	1,146	2	573
MxDxR	4	1	4
MxLxR	131	2	66
PxSxD	165	1	165
PxSxL	135	2	68
PxSxR	269	1	269
PxDxL	87	2	44
PxDxR	34	1	34
PxLxR	24	2	12
SxDxL	150	2	75
SxDxR	140	1	140
SxLxR	3,866	2	1,933**
DxLxR	480	2	240
Residual	44,843	242	185
Total	312,928	383	134,777

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 9. Analysis of Variance of the Per Cent Good in the Pickouts for Operator 1.

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
M	0.05	1	0.05
P	3.38	1	3.38
S	7.05	1	7.05
D	54.01	1	54.01**
L	19.40	2	9.70*
R	1.51	1	1.51
MxP	11.04	1	11.04*
MxS	1.49	1	1.49
MxD	0.03	1	0.03
MxL	0.27	2	0.14
MxR	0.36	1	0.36
PxS	4.16	1	4.16
PxD	2.03	1	2.03
PxL	0.44	2	0.22
PxR	2.03	1	2.03
SxD	0.03	1	0.03
SxL	3.39	2	1.69
SxR	3.36	1	3.36
DxL	9.81	2	4.91
DxR	0.15	1	0.15
LxR	3.81	2	1.91
MxPxS	0.00	1	0.00
MxPxD	10.30	1	10.30*
MxPxL	8.76	2	4.38
MxPxR	20.39	1	20.39**
MxSxD	0.18	1	0.18
MxSxL	1.19	2	0.59
MxSxR	0.19	1	0.19
MxDxL	1.02	2	0.51
MxDxR	1.06	1	1.06
MxLxR	1.69	2	0.89
PxSxD	8.18	1	8.18
PxSxL	1.02	2	0.51
PxSxR	1.52	1	1.52

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 9. Analysis of Variance of the Per Cent Good in the Pickouts for Operator 1.

(Continued)

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
PxDxL	0.27	2	0.14
PxDxR	0.06	1	0.06
PxLxR	5.02	2	2.51
SxDxL	1.65	2	0.83
SxDxR	0.06	1	0.06
SxLxR	7.57	2	3.79
DxLxR	0.40	2	0.20
Residual	51.03	38	1.34
Total	249.34	95	166.88

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 10. Analysis of Variance of the Per Cent Good in the Pickouts for Operators 2 and 3.

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
O	4,971	1	4,971 **
M	837	1	837 **
P	26	1	26
S	1,266	1	1,266 **
D	1,022	1	1,022 **
L	1,683	2	841.5**
R	323	1	323 **
OxM	1,127	1	1,127 **
OxP	1	1	1
OxS	1	1	1
OxD	241	1	241 **
OxL	138	2	69
OxR	198	1	198 *
MxP	48	1	48
MxS	53	1	53
MxD	14	1	14
MxL	14	2	7
MxR	7	1	7
PxS	11	1	11
PxD	1	1	1
PxL	25	2	12.5
PxR	51	1	51
SxD	95	1	95
SxL	801	2	400.5**
SxR	5	1	5
DxL	45	2	22.5
DxR	64	1	64
LxR	125	2	62.5
OxMxP	82	1	82
OxMxS	28	1	28
OxMxD	32	1	32
OxMxL	25	2	12.5
OxMxR	131	1	131

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 10. Analysis of Variance of the Per Cent Good in the Pickouts for Operators 2 and 3.

(Continued)

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
OxPxS	7	1	7
OxPxD	3	1	3
OxPxL	20	2	10
OxPxR	3	1	3
OxSxD	64	1	64
OxSxL	99	2	49.5
OxSxR	1	1	1
OxDxL	79	2	39.5
OxDxR	122	1	122
OxLxR	79	2	39.5
MxPxS	47	1	47
MxPxD	21	1	21
MxPxL	12	2	6
MxPxR	7	1	7
MxSxD	21	1	21
MxSxL	48	2	24
MxSxR	3	1	3
MxDxL	34	2	17
MxDxR	2	1	2
MxLxR	10	2	5
PxSxD	0	1	0
PxSxL	17	2	8.5
PxSxR	6	1	6
PxDxL	11	2	5.5
PxDxR	8	1	8
PxLxR	2	2	1
SxDxL	58	2	29
SxDxR	16	1	16
SxLxR	181	2	90.5
DxLxR	45	2	22.5
Residual	2,373	106	22.4
Total	16,890	191	12,763.9

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 11. Analysis of Variance of the Per Cent Good in the Pickouts for Operator 4.

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
M	2	1	2
P	190	1	190 **
S	882	1	882 **
D	68	1	68 **
L	497	2	248.5**
R	1,496	1	1,496 **
MxP	1	1	1
MxS	2	1	2
MxD	11	1	11
MxL	7	2	3.5
MxR	39	1	39 **
PxS	25	1	25 **
PxD	16	1	16
PxL	3	2	1.5
PxR	6	1	6
SxD	79	1	79 **
SxL	215	2	107.5**
SxR	244	1	244 **
DxL	88	2	44 **
DxR	3	1	3
LxR	36	2	18 *
MxPxS	5	1	5
MxPxD	14	1	14
MxPxL	41	2	20.5*
MxPxR	5	1	5
MxSxD	6	1	6
MxSxL	7	2	3.5
MxSxR	33	1	33 **
MxDxL	60	2	30 *
MxDxR	10	1	10
MxLxR	3	2	1.5

** Significant at the 0.001 level.
* Significant at the 0.01 level.

Table 11. Analysis of Variance of the Per Cent Good in the Pickouts for Operator 4.

(Continued)

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares
PxSxD	8	1	8
PxSxL	3	2	1.5
PxSxR	2	1	2
PxDxL	13	2	6.5
PxDxR	422	1	422 **
PxLxR	17	2	8.5
SxDxL	25	2	12.5*
SxDxR	55	1	55 **
SxLxR	340	2	170 **
DxLxR	188	2	94 **
Residual	90	38	2.4
Total	5,257	95	4,397.9

** Significant at the 0.001 level.
* Significant at the 0.01 level.

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